**The Birth of the Universe**

22.1 Multiple-Choice Questions

1) To date, physicists have investigated the behavior of matter and energy at temperatures as high as those that existed in the universe as far back as \_\_\_\_\_\_\_\_ after the Big Bang.

A) 1 million years

B) 300,000 years

C) 300 years

D) 3 minutes

E) 10-10 second

Answer: E

2) How long after the Big Bang was the *Planck time*, before which our current theories are completely unable to describe conditions in the universe?

A) 10-10 second

B) 10-35 second

C) 10-43 second

D) 3 minutes

E) 300,000 years

Answer: C

3) The Planck era refers to the time period

A) before the Big Bang.

B) before the Planck time.

C) after the Planck time.

D) after inflation.

E) after the GUT era.

Answer: B

4) Why can't current theories describe what happened during the Planck era?

A) We do not yet have a theory that links quantum mechanics and general relativity.

B) We do not understand the properties of antimatter.

C) We do not know how much energy existed during that time.

D) It was a time period from which we cannot receive radiation.

E) The Planck era was the time before the Big Bang, and we cannot describe what happened before that instant.

Answer: A

5) A GUT (grand unified theory) refers to theories that

A) unify all four forces.

B) unify gravity and the electromagnetic and weak forces.

C) unify gravity and the strong and weak forces.

D) unify the strong force and the electromagnetic and weak forces.

E) unify the electromagnetic and weak forces.

Answer: D

6) When we say that the electromagnetic and weak forces "freeze out" from the electroweak force at 10-10 seconds after the Big Bang, we mean that

A) these forces are important only at temperatures below the freezing point of water–a temperature that the universe reached at an age of about 10-10 second.

B) "freezing out" was a term coined by particle physicists who think that the Big Bang theory is really cool.

C) prior to this time the electromagnetic and weak forces maintained a single identity, but they possessed separate identities following this time.

D) following this time neither the electromagnetic nor the weak force was ever important in the universe again.

E) quantum fluctuations by high-speed, relativistic particles in a state of false vacuum cause disturbances in the spacetime continuum, leading to the process described in the question this answer refers to.

Answer: C

7) How many forces operated in the universe during the GUT era?

A) one, what we call the "super force"

B) two, gravity and the GUT force

C) two, gravity and the electroweak force

D) three, gravity, the strong force, and the electroweak force

E) all of the above forces

Answer: B

8) Which forces have physicists shown to be the same force under conditions of very high temperature or energy, as confirmed by experiments in particle accelerators?

A) gravity and the weak force

B) gravity and the strong force

C) the strong and weak forces

D) the strong and electromagnetic forces

E) the electromagnetic and weak forces

Answer: E

9) What do we mean by *inflation*?

A) what happened the instant after the Big Bang

B) a sudden expansion of the universe after the strong force froze out from the GUT force

C) the expansion of the universe that we still observe today

D) the sudden release of photons when a particle and antiparticle annihilate each other

E) the separation that occurs after two photons collide and create a particle and an antiparticle

Answer: B

10) (From a science quiz that appeared in the weekly magazine *The Economist.*) Economic history is easier to write than the history of the universe. Nevertheless, most cosmologists now think that when the universe was formed,

A) first there was a Big Bang, then inflation (of space) caused recession (of all matter, away from the Big Bang).

B) first there was inflation, which caused the Big Bang, then recession.

C) first there was a Big Bang. There has not been any inflation yet, but if it comes it will cause recession.

Answer: A

11) Why might inflation have occurred at the end of the GUT era?

A) Gravity was an extremely weak force at this period in time.

B) Large amounts of matter and antimatter annihilated at this time.

C) There wasn't enough matter present to slow down the expansion at that time.

D) The universe was too small and needed to grow quickly.

E) An enormous amount of energy was released when the strong force froze out from the GUT force.

Answer: E

12) What direct evidence do we have that the weak and electromagnetic forces were once unified as a single electroweak force?

A) The most advanced telescopes are able to see back to this era in the universe.

B) Detectors on Earth have received photons and high-energy particles from this era.

C) Temperatures in the center of the Sun can reproduce the conditions during this era.

D) Particle accelerators on Earth can reach energies equivalent to the high temperatures of this era and have produced particles predicted by the electroweak theory.

E) We have no direct evidence of the electroweak force.

Answer: D

13) What happened to the quarks that existed freely during the particle era?

A) They combined in groups to make protons, neutrons, and their antiparticles.

B) They froze out of the soup of particles at the end of the era.

C) They evaporated.

D) They combined in groups to make electrons and neutrinos.

E) They combined in groups to make W and Z bosons.

Answer: A

14) Approximately how long did the *era of nucleosynthesis* last?

A) 10-10 second

B) 0.001 second

C) 5 seconds

D) 5 minutes

E) 5 years

Answer: D

15) What kinds of atomic nuclei formed during the *era of nucleosynthesis*?

A) only hydrogen

B) only helium

C) hydrogen and helium and trace amounts of deuterium and lithium

D) roughly equal amounts of each of the following: hydrogen, helium, deuterium and lithium

E) nuclei of all the chemical elements

Answer: C

16) Why is the *era of nucleosynthesis* so important in determining the chemical composition of the universe?

A) All the elements except hydrogen were produced after the era of nucleosynthesis.

B) We can observe spectra from this era to determine what the primordial mix of the elements was at the beginning of the universe.

C) Except for the small amount of matter produced later by stars, the chemical composition of the universe is the same now as at the end of the era of nucleosynthesis.

D) We can study the processes that occurred during the era of nucleosynthesis to determine how most of the elements in the universe were created.

E) By knowing how much matter was created during the era of nucleosynthesis, we can determine whether the universe is open or closed.

Answer: C

17) Why did the *era of nuclei* end when the universe was about 300,000 years old?

A) All the free particles had combined to form the nuclei of atoms.

B) The universe had expanded and cooled to a temperature of about 3,000 K, cool enough for stable, neutral atoms to form.

C) Neutrinos and electrons were finally able to escape the plasma of the early universe and no longer heated the other particles.

D) Photons were finally able to escape the plasma of the early universe and no longer heated the hydrogen and helium ions.

E) No theory can explain this.

Answer: B

18) Evidence that the cosmic background radiation really is the remnant of a Big Bang comes from *predicting* characteristics of remnant radiation from the Big Bang and *comparing* these predictions with observations. Four of the five statements below are real. Which one is fictitious?

A) The cosmic background radiation is expected to have a temperature just a few degrees above absolute zero, and its actual temperature turns out to be about 3 K (actually 2.7 K).

B) The cosmic background radiation is expected to have a perfect thermal spectrum, and observations from the COBE spacecraft verify this prediction.

C) The cosmic background radiation is expected to contain spectral lines of hydrogen and helium, and it does.

D) The cosmic background radiation is expected to look essentially the same in all directions, and it does.

E) The cosmic background radiation is expected to have tiny temperature fluctuations at the level of about 1 part in 100,000. Such fluctuations were found in the COBE data.

Answer: C

19) Which of the following statements about the cosmic background radiation is *not* true?

A) It has a temperature of about 3 degrees K above absolute zero.

B) It is the result of a mixture of radiation from many independent sources, such as stars and galaxies.

C) It had a much higher temperature in the past.

D) It was discovered by Penzias and Wilson in the early 1960s.

E) It appears essentially the same in all directions (it is isotropic).

Answer: B

20) Where do the photons in the cosmic background radiation originate?

A) the moment of the Big Bang

B) the end of the Planck era

C) during the era of nucleosynthesis

D) the end of the era of nuclei

E) during the era of galaxy formation

Answer: D

21) Why does the Big Bang theory predict that the cosmic background radiation should have a perfect thermal radiation spectrum?

A) The background radiation came from the heat of the universe, with a peak corresponding to the temperature of the universe.

B) The spectrum of pure hydrogen is a perfect thermal radiation spectrum.

C) The spectrum of 75 percent hydrogen and 25 percent helium is a perfect thermal radiation spectrum.

D) The light from all the stars and gas in the sky averaged over the entire universe is a perfect thermal radiation spectrum.

E) It *doesn't* predict that the cosmic background radiation should have a perfect thermal radiation spectrum.

Answer: A

22) Why do we expect the cosmic background radiation to be almost, but not quite, the same in all directions?

A) The overall structure of the universe is very uniform, but the universe must have contained some regions of higher density in order for galaxies to form.

B) The temperature of the universe can be found by taking an average over the entire sky, but individual stars will create peaks in the spectrum over small angles.

C) Dark matter consisting of WIMPs greatly smooths out the spectrum, but the small patches of "light" matter create peaks in the spectrum.

D) The overall structure of the universe is very uniform, but the synthesis of different elements produces varying signatures within the background spectrum.

E) The overall structure of the universe is very uniform, but intervening gas between us and the era of nuclei absorbs wavelengths depending on the composition and redshift of the gas.

Answer: A

23) Helium originates from

A) stellar nucleosynthesis only.

B) the Big Bang only.

C) stellar nucleosynthesis with a small contribution from the Big Bang.

D) the Big Bang with a small contribution from stellar nucleosynthesis.

E) radioactive decay of heavier elements only.

Answer: D

24) What are the two key observational facts that led to widespread acceptance of the Big Bang model?

A) the cosmic background radiation and the high helium content of the universe

B) the cosmic background radiation and the expansion of the universe

C) the cosmic background radiation and the near-critical density of the universe

D) the predominance of matter over antimatter and the near-critical density of the universe

E) the predominance of matter over antimatter and the large scale structure of galaxies

Answer: A

25) Why do we think tiny quantum ripples should have been present in the very early universe?

A) The shock wave of the Big Bang caused ripples that expanded outward with time.

B) The energy released when the strong force froze out of the GUT force caused shock waves that produced ripples in the universe.

C) Matter and antimatter particles that spontaneously formed from high-energy photons caused perturbations in the radiation field.

D) The annihilation of matter and antimatter particles caused tiny explosions that perturbed the radiation field.

E) Quantum mechanics requires that the energy fields at any point in space be continually fluctuating as a result of the uncertainty principle.

Answer: E

26) What is postulated to have caused a sudden inflation of the early universe?

A) the annihilation of matter and antimatter

B) the separation of the electromagnetic and weak forces

C) the "freezing out" of the strong force from the GUT force

D) the energy released in the fusion of protons and neutrons to produce helium

E) giant quantum fluctuations

Answer: C

27) Olbers' paradox is an apparently simple question, but its resolution suggests that the universe is finite in age. What is the question?

A) What would it be like to ride on a beam of light?

B) Can we measure the position and momentum of an electron at the same time?

C) How does the Sun produce energy?

D) Why is the sky dark at night?

E) How many stars are in the universe?

Answer: D

*Refer to this scenario for the following questions:*

Lost in Spacetime. Just when you thought it was safe to take final exams . . . a vindictive multi-dimensional being reaches down (up? over? through?) to Earth and pulls you out of the universe. You are thrown back into the universe at a place of this being's choosing, and she permits you to leave only after you have identified your surroundings. You are subject to several tests.

Through a scientifically unexplainable miracle, you are able to survive in every one of the places you are tested. (Lest you become too comfortable, however, you certainly *are* able to feel any associated pain due to high temperature, pressure, gravity, etc.) In each case described below, identify your surroundings. In some cases, the surroundings described may exist only during eras of the universe (past or future) other than our own time; in those cases, you should identify both the place and the *time* where you are located.

28) You find yourself in a place that looks (except for your own presence) perfectly symmetrical. There is no way to distinguish one place from another, and all forces are one. With this perfect symmetry, there is no obvious way to define the flow of time. Where are you?

A) You are in the center of a young star.

B) You are in the early universe before the Planck time.

C) You are floating somewhere in the universe near its end, 10100 years from now.

D) You are inside the nucleus of an atom.

E) You are in the universe shortly after inflation.

Answer: B

29) You are in a place that is extremely hot and dense, making you feel quite sweaty and claustrophobic. You can't see far because your surroundings are opaque to light. Around you, nuclear fusion is converting carbon into oxygen and other elements. Where are you?

A) You are in the center of a star very much like our Sun.

B) You are in the early universe during the era of nucleosynthesis.

C) You are inside a nuclear power plant on Earth.

D) You are in the center of a massive star near the end of its life.

E) You are in the center of a star much smaller than the Sun.

Answer: D

30) You are on the surface of an object, and you have a fairly clear view out into space. It might be very nice, except for one major drawback: You are *very* squashed. Also, light you observe from distant objects is apparently slightly blueshifted (compared to what it normally looks like). The surface of the object is composed primarily of carbon and oxygen, and the horizon distance is about the same as that on Earth. By observing the stellar background for a few weeks, you realize that there are several planets orbiting your object. Where are you?

A) You are on the surface of Earth.

B) You are on the surface of a planet that is somewhat more massive than Earth.

C) You are on the surface of a white dwarf.

D) You are "on" an accretion disk around a black hole.

E) You are on the surface of a neutron star.

Answer: C

31) It sure is bright *everywhere*; you've been able to travel around a bit, and it's clear that you are not in a star. Yet it is as bright as looking directly at the Sun. In your extensive travels through your current surroundings, you cannot find a single neutral atom anywhere, nor can you find a nucleus besides hydrogen or helium. And, while it is hot (a few thousand degrees Kelvin), it is nowhere near the temperature needed for nuclear fusion. Where are you?

A) You are in the universe during its first 300,000 years.

B) You are in the universe more than 10100 years in the future.

C) You are in an accretion disk around a supermassive black hole.

D) You are in the central regions of a quasar.

E) You are where the Sun should be located, but about 5 billion years from now.

Answer: A

32) You are feeling like spaghetti. Although normally only about 2 meters tall, you are now about 25 meters long. (How fortunate, if painful, that the being has arranged for your body to become elastic enough so that it is not ripped apart under these conditions.) As you look up over your head, you see things moving pretty quickly in the universe–but that lasts only for a brief instant, and then all contact with the universe is lost. Where are you?

A) You are plunging into the Sun.

B) You are crossing the event horizon of a black hole.

C) You are being consumed by a "crack" in the universe caused by inflation.

D) You are near the center of a star that has just developed an iron core, leading to a supernova.

E) You are in a medieval torture chamber somewhere in western Europe.

Answer: B

33) You are once again in a hot, dense place. You are surrounded by protons and neutrons, some rapidly fusing into helium. You notice that your surroundings are cooling (good, because it's really hot!) and rapidly dropping in density. Within about 3 minutes, the fusion reactions stop. Where are you?

A) You are in the center of a star very much like our Sun.

B) You are in the early universe during the era of nucleosynthesis.

C) You are inside a nuclear power plant on Earth.

D) You are in the center of a star much smaller than the Sun.

E) You are in the center of a massive star near the end of its life.

Answer: B

34) At last you are in a place where the heat and high density are no longer bothering you. However, although the density is very low, the gas around you is extremely high in temperature. In fact, the temperature is so high that it is emitting lots of X rays, which are creating cancer-causing mutations in your body at a rapid rate. Well, at least the view is great! There are no stars anywhere within about 10,000 light-years of you, but at slightly greater distances your sky is brightened by many beautiful, star-filled structures, some with majestic spiral shapes. Where are you?

A) You are in the universe when it was about 200 million years old, just before galaxies began forming.

B) You are in the center of the Milky Way Galaxy, looking outward into the Local Group.

C) You are somewhere between the Andromeda and Milky Way galaxies in the Local Group.

D) You are in intergalactic space within a rich cluster of thousands of galaxies.

E) You are in the outskirts of a galaxy whose nucleus is a powerful quasar.

Answer: D

35) At last, someplace fairly comfortable. Very weak gravity is holding you to the surface of the small object on which you sit. Your object is apparently moving away from a star, perhaps one that it orbits with a period of thousands of years. Around you, geysers are spouting gas into space. Looking back along the object's orbit, you see particles of dust that the geysers apparently blew off the object when it was nearer to the star that it is now leaving behind. You conclude that the geysers were recently much more active but are now settling down into a quiescent state that may last for millennia. You also soon realize that you are closer to home than you have been in all your previous journeys. Perhaps if you can somehow find a small rocket, a heat shield, and a good parachute, you can escape and head home for your final exam. Where are you?

A) You are on an asteroid near the center of a galaxy, heading in toward a massive black hole.

B) You have been shrunk in size and are riding a grain of interstellar dust that is carrying you on an orbit about our very own Sun.

C) You are riding a jet of gas from a quasar that is headed in the direction of an ordinary star.

D) You are on comet Hale-Bopp, circa May 1997.

E) You are at Disneyland on the Moon, riding the new "wild and wet" roller coaster.

Answer: D

36) Which of the following observations is not a piece of evidence supporting the Big Bang theory?

A) Darkness of the night sky

B) Recession speeds of far away galaxies relative to close ones

C) Observed helium abundance in the universe

D) Relative motions of galaxies in the Local Group

Answer: D

22.2 True/False Questions

1) The *Planck era* is another name for the present period of time in the universe.

Answer: FALSE

2) The observed composition of ordinary matter in the universe–roughly 75 percent hydrogen and 25 percent helium–closely matches theoretical predictions based on the Big Bang model.

Answer: TRUE

3) GUT theories predict that protons will eventually decay, causing all solid objects in the universe to fall apart if the universe keeps expanding forever.

Answer: TRUE

4) The theory that inflation occurred in the early universe is incompatible with the theory of relativity.

Answer: FALSE

5) If inflation really occurred, then our *observable universe* is only a tiny portion of the entire universe born in the Big Bang.

Answer: TRUE

6) Observations of the cosmic background radiation from the COBE satellite revealed tiny variations in its temperature from one place to another (corresponding to a few millionths of a degree Kelvin).

Answer: TRUE

7) The Big Bang predicts that one in four atoms in the universe is helium.

Answer: FALSE

8) Current measurements of the density of the universe support the prediction of the theory of inflation that the universe should be flat.

Answer: FALSE

9) The fact that the sky is dark at night shows that the observable universe cannot extend forever.

Answer: TRUE

10) *Process of Science:* Inflation can explain some general features of the Universe but it is not directly testable and cannot be considered a theory.

Answer: FALSE

22.3 Short Answer Questions

1) Briefly explain how Hubble's discovery of a relationship between galactic distance and redshift led to the idea of the Big Bang.

Answer: Hubble's discovery showed that the universe is expanding. If the universe is expanding, then logically it seems that it should have been smaller in the past. Extrapolating back in time, there must have been a time when everything was in one place–which we call the Big Bang.

2) What do we mean by *inflation*, and why might it have occurred at the end of the GUT era?

Answer: The inflation of the universe occurred over a period of 10-33 seconds in which time the universe underwent a sudden and dramatic expansion. The universe may have grown from a size much smaller than the nucleus of an atom to many meters across during this time. Inflation might have occurred at the end of the GUT era when the strong force froze out of the GUT force. This event would have released an enormous amount of energy that could have caused this expansion.

3) Why is the *era of nucleosynthesis* so important in determining the chemical composition of the universe forever after?

Answer: The era of nucleosynthesis is important because during this time all the primordial hydrogen and helium was created from the nuclear fusion process. Except for the few percent of matter that stars later fused into heavier elements, the chemical composition of the universe remains unchanged today.

4) Briefly explain why radiation was trapped for 300,000 years during the *era of nuclei*, and why the cosmic background radiation broke free at the end of this era.

Answer: During the era of nuclei, the universe consisted of a hot plasma of hydrogen nuclei, helium nuclei, and free electrons. Throughout this era, photons bounced rapidly from one electron to the next, just as they do deep inside the Sun today, never managing to travel far between collisions. If a nucleus managed to capture an electron to form a neutral atom, one of the photons quickly ionized it. This era came to an end when the expanding universe had cooled down to about 3,000 K. At this temperature, the hydrogen and helium nuclei were able to capture electrons and form stable, neutral atoms for the first time. With electrons bound into atoms, the photons began to stream freely across the universe.

5) Briefly describe the two key pieces of evidence that support the Big Bang theory.

Answer: The two key pieces of evidence that support the Big Bang theory are the cosmic background radiation and the observed helium content of the universe. The cosmic background radiation consists of photons arriving at Earth directly from the end of the era of nuclei. The radiation came from the heat of the universe and should have a thermal radiation spectrum with a peak wavelength corresponding to 3,000 K, the temperature the universe was at the end of that era. Since the universe has expanded by a factor of about 1,000 since that time, we observe the radiation with a peak wavelength of about a millimeter, corresponding to a temperature of 2.73 K. The Big Bang theory predicts that the universe should have had a composition of 75 percent hydrogen and 25 percent helium by mass at the end of the era of nucleosynthesis. The Milky Way's helium fraction is about 28 percent, and no galaxy has a helium fraction lower than 25 percent.

6) What did COBE find regarding the smoothness of the cosmic background radiation?

Answer: COBE found that the cosmic background radiation has a perfect thermal radiation spectrum, with a peak corresponding to a temperature of 2.73 K. However, it also found slight fluctuations in the radiation. The temperature varies very slightly from one place to another by a few parts in 100,000.

7) Why didn't the Big Bang produce many heavier elements than helium?

Answer: By the time helium nuclei could exist in large numbers without being destroyed by the intense radiation field, the universe was about a minute old and the temperature and density were rapidly decreasing. Nuclear fusion reactions to produce heavier elements were possible, but the combination of two helium nuclei or a hydrogen nucleus and helium nucleus produces unstable nuclei. The combination of three helium nuclei produce carbon, but by this time the density of the universe was too low for many three-body collisions to occur. Thus the production of heavier elements had to wait until stellar nucleosynthesis.

8) What is Olber's paradox and what is its resolution?

Answer: If the universe were infinite and unchanging, the night sky should be as bright as the Sun because every line of sight should eventually end up looking at the surface of a star somewhere and the total of all this light would make for a uniformly bright sky. Yet clearly it becomes dark when the Sun sets and that is the paradox. The resolution to this is for the universe to be either finite or changing. In particular, if the universe had a beginning then we can only see a finite number of stars–those that lie within our cosmological horizon–and thus we can have a dark night sky.

9) Briefly describe one of the three quandaries that are solved by inflation; that is, describe either the *structure problem*, the *smoothness problem*, or the *flatness problem*.

Answer: *Structure problem:* The fact that there are galaxies means that the density of the early universe differed slightly from place to place. The temperature differences in the cosmic background radiation show that regions of enhanced density did exist at the end of the era of nuclei, when the universe was 300,000 years old. However, the standard Big Bang theory cannot explain where these density enhancements originally came from.

*Smoothness problem:* Observations of the cosmic background radiation show that the density of the universe at the end of the era of nuclei varied from place to place by no more than about 0.01 percent. This means that two regions of the universe that have not had time to be in contact with each other yet are almost at exactly the same temperature. The coincidence that almost the entire universe would be in equilibrium without having contact among various regions is almost impossible.

*Flatness problem:* The density of the matter in the universe is around 20-100 percent of the critical density. Since the Big Bang theory does not state anything about what the density of the universe should be, why would it be so close to this density? Another way to state this problem is to say that the universe is very flat. If the universe had been 10 percent denser at the end of the era of nuclei, it would have recollapsed long ago. If it had been 10 percent less dense at this time, galaxies would never have formed before expansion spread the matter too thin.

10) What is meant by the microwave observations of the cosmic background radiation revealing the "genetic code" of the universe?

Answer: The latest microwave observations of the cosmic microwave background are sensitive enough to detect tiny temperature variations across the sky. These correspond to slight density enhancements at the end of the era of nuclei which magnified under the force of gravity to become the large scale structures–voids, superclusters, etc.–that we see at the present time. The present conditions of the universe are dependent on the structure of these initial density fluctuations, and for this reason it is analogous to the genetic code of DNA in a living organism.

11) *Process of Science:* Why do we test theories about the Big Bang using particle accelerators instead of just using bigger and bigger telescopes to look further back in time?

Answer: The Universe was so small and hot during the early phases of the Big Bang that there was spontaneous particle creation from energy and annihilation. We can recreate the conditions of particle creation and annihilation at high energies using particle accelerators and thereby test theories of the Big Bang. Furthermore, we cannot actually see these early stages directly because the Universe is so dense that it is opaque.

22.4 Mastering Astronomy Reading Quiz

1) Based on our current understanding of physics, we can understand the conditions that prevailed in the early universe as far back in time as about

A) 380,000 years after the Big Bang.

B) one ten-billionth of a second after the Big Bang.

C) 10-45 seconds after the Big Bang.

D) 10 billion years ago.

Answer: B

2) What happens when a particle of *matter* meets its corresponding antiparticle of antimatter?

A) They can form a complete atom.

B) The combined mass of the two particles is completely transformed into energy (photons).

C) They fuse to make a heavier particle.

D) The question makes no sense, since antimatter does not really exist.

Answer: B

3) What is the significance of the *Planck time*?

A) It is the time at which inflation is thought to have occurred.

B) Before it, conditions were so extreme that our current understanding of physics is insufficient to predict what might have occurred.

C) It is the time when the cosmic microwave background was released.

D) It is the amount of time required for two protons to fuse to make deuterium.

Answer: B

4) The four fundamental forces that operate in the universe today are

A) strong force, weak force, electromagnetic force, gravity.

B) strong force, weak force, electric force, magnetic force.

C) nuclear force, electromagnetic force, gravity, tidal force.

D) nuclear force, gravity, electric force, magnetic force.

Answer: A

5) A "GUT" (grand unified theory) refers to theories that

A) unify gravity with the strong and weak forces.

B) unify the electromagnetic and weak forces.

C) unify all four forces together.

D) unify the strong force with the electromagnetic and weak forces.

Answer: D

6) What do we mean by *inflation*?

A) the expansion of the universe that we still observe today

B) the sudden release of photons when a particle and antiparticle annihilate one another

C) a sudden and extremely rapid expansion of the universe that occurred in a tiny fraction of a second during the universe's first second of existence

D) quantum fluctuations by high speed, relativistic particles in a state of false vacuum that caused disturbances in the space-time continuum leading to the process described in the question to which this answer refers

Answer: C

7) Which of the following statements correctly summarizes the events in the early universe according to the Big Bang theory?

A) The universe began with the forces unified. During the first fraction of a second, the forces separated and there was a brief but important episode of inflation. Subatomic particles of both matter and antimatter then began to appear from the energy present in the universe. Most of the particles annihilated to make photons, but some became protons, neutrons, electrons, and neutrinos. The protons and neutrons underwent some fusion during the first three minutes, thereby determining the basic chemical composition of the universe.

B) An episode of what we call inflation initiated the event of the Big Bang. Once the Big Bang got underway, particles and forces began to appear one by one. The forces produced protons, which fused to make hydrogen and helium until the universe was about 380,000 years old. Then gravity began to act, turning the hydrogen and helium into galaxies.

C) Forces and various subatomic particles began to appear during the first second after the Big Bang. For reasons not understood, the particles were all made of ordinary matter and none were made of antimatter, thus explaining why we live in a universe made of matter. The particles underwent some fusion for the first 380,000 years after the Big Bang, at which time the first stars were born.

D) The Big Bang began with the initiation of what we call inflation, which gradually slowed to the current expansion rate of the universe. Forces came to exist for a different reason, having to do with quantum fluctuations in the space-time continuum. Particles came to exist as a result of cracks made when forces froze. Once there were particles, gravity brought them together to make stars, and the stars then turned the particles into hydrogen, helium, and other elements.

Answer: A

8) Which statement about the cosmic microwave background is *not* true?

A) Its spectrum corresponds to a temperature of just under 3 degrees above absolute zero.

B) With the exception of very small variations, it appears essentially the same in all directions in which we look into space.

C) It is the result of a mixture of radiation from many independent sources, such as stars and galaxies.

D) It is thought to be radiation that began its journey to our telescopes when the universe was about 380,000 years old.

Answer: C

9) The Big Bang theory is supported by two major lines of evidence that alternative models have not successfully explained. What are they?

A) (1) the theory correctly predicts that the universe should be expanding; (2) the theory predicts the existence of and the specific characteristics of the observed cosmic microwave background

B) (1) the theory predicts the episode of inflation that we think occurred in the early universe; (2) the theory predicts the existence of large quantities of dark matter.

C) (1) the theory correctly predicts that the universe should be expanding; (2) the theory correctly predicts the observed ratio of spiral to elliptical galaxies in the universe.

D) (1) the theory predicts the existence of and the specific characteristics of the observed cosmic microwave background; (2) the theory correctly predicts the observed overall chemical composition of the universe.

Answer: D

10) Measuring the amount of deuterium in the universe allows us to set a limit on

A) the total amount of mass in the universe.

B) the density of ordinary (baryonic) matter in the universe.

C) the acceleration of the universe.

D) the current age of the universe.

Answer: B

11) The idea of dark matter arose to explain gravitational effects observed in galaxies and clusters of galaxies. However, studies of the early universe (especially of the cosmic microwave background and of chemical abundances) also tell us something about dark matter. What do they tell us?

A) They add further support to the idea that dark matter really exists and is made of non-ordinary (nonbaryonic) matter, such as WIMPs.

B) They do not support the conclusion that dark matter is the dominant form of matter in the universe.

C) They tell us that dark matter probably exists, but that it must be made of ordinary (baryonic) matter in the form of MACHOs.

D) They tell us that dark matter was produced during the era of nuclei.

Answer: A

12) Which of the following observations cannot be explained by the Big Bang theory *unless* we assume that an episode of inflation occurred?

A) the fact that the temperature of the cosmic microwave background is almost the same everywhere

B) the fact that about 25% of the ordinary matter in the universe consists of helium

C) the existence of the cosmic microwave background

D) the fact that the universe is expanding

Answer: A

13) The idea of inflation makes one clear prediction that, until the discovery of an accelerating expansion, seemed to contradict the available observations. What is this prediction?

A) Inflation predicts that the early universe should have regions of enhanced density that could have acted as "seeds" for the formation of galaxies and large structures.

B) The universe should be geometrically "flat" (in the four dimensions of spacetime).

C) Inflation predicts that the temperature of the cosmic microwave background should be almost (but not exactly) the same everywhere.

D) Inflation predicts that the entire universe must be far larger than the observable universe.

Answer: B

14) *Olbers's paradox* is an apparently simple question, but its resolution suggests that the universe is finite in age. What is the question?

A) What would it be like to ride on a beam of light?

B) How many stars are in the universe?

C) Can we measure the position and momentum of an electron at the same time?

D) Why is the sky dark at night?

Answer: D

15) What is the temperature of the universe (as a whole) today?

A) 3K

B) 300K

C) 3000K

D) The universe cannot be said to have a single temperature.

Answer: A

16) Which of the following statements *cannot* be tested by science today?

A) Our universe is flat.

B) Prior to the Planck time, our universe sprouted from another universe.

C) The universe is 14 billion years old.

D) The expansion of the universe is now accelerating.

Answer: B

22.5 Mastering Astronomy Concept Quiz

1) How do we determine the conditions that existed in the very early universe?

A) We look all the way to the cosmological horizon, where we can see the actual conditions that prevailed all the way back to the first instant of the Big Bang.

B) The conditions in the very early universe must have been much like those found in stars today, so we learn about them by studying stars.

C) We work backward from current conditions to calculate what temperatures and densities must have been when the observable universe was much smaller in size.

D) We can only guess at the conditions, since we have no way to calculate or observe what they were.

Answer: C

2) Why can't current theories describe what happened during the Planck era?

A) We do not know how hot or dense the universe was during that time.

B) We do not understand the properties of antimatter.

C) We do not yet have a theory that links quantum mechanics and general relativity.

D) The Planck era was the time before the Big Bang, and we cannot describe what happened before that instant.

Answer: C

3) Which of the following statements best explains what we mean when we say that the electroweak and strong forces "froze out" at 10-38 second after the Big Bang?

A) These two forces first became distinct at this time.

B) These forces are important only at temperatures below the freezing point of water—a temperature that the universe reached at an age of about at 10-38 second.

C) *Freezing out* was a term coined by particle physicists who think that the Big Bang theory is really cool.

D) Following this time, neither the strong nor electroweak forces were ever important in the universe again.

Answer: A

4) According to the Big Bang theory, how many forces—and which ones—operated in the universe during the *GUT era*?

A) 1 force that represented the unification of all four forces that operate today

B) 3 forces: gravity, the strong force, and the electroweak force

C) 2 forces: the strong force and the electroweak force

D) 2 forces: gravity and a single force that later became the strong, weak, and electromagnetic forces

Answer: D

5) Laboratory experiments conducted with particle accelerators confirm predictions made by the theory that unifies

A) the electromagnetic and weak forces into the electroweak force.

B) the strong, weak, and electromagnetic forces into the GUT force.

C) the unification of all four forces into a single "superforce."

D) the strong and weak forces into the combined nuclear force.

Answer: A

6) What was the significance of the end of the *era of nucleosynthesis*, when the universe was about 5 minutes old?

A) The proportions of dark matter and luminous matter had been determined.

B) The basic chemical composition of the universe had been determined.

C) It marks the time at which the first stars formed.

D) It marks the time at which the expansion of the universe had settled down to its current rate.

Answer: B

7) According to the Big Bang theory, why do we live in a universe that is made of almost entirely of matter rather than antimatter?

A) During the first 0.001 second after the Big Bang, particles and antiparticles were made in almost but not perfectly equal numbers. Everything annihilated except the very slight excess of matter particles.

B) GUT theories predict that under the conditions that prevailed in the early universe, the normal laws of physics would have been suspended so that only matter particles were created, and no particles of antimatter.

C) The fact that we live in a universe made of matter is not surprising, because antimatter has never been shown to exist for real.

D) Einstein's famous equation *E = mc2* tells us that energy can turn into matter, but does not tell us that it can turn into antimatter.

Answer: A

8) Which of the following is *not* an observed characteristic of the cosmic microwave background?

A) It has a perfect thermal radiation spectrum.

B) Its temperature is the same everywhere, except for small variations at the level of 1 part in 100,000.

C) Its temperature is a little less than 3 Kelvin (3 degrees above absolute zero).

D) It contains prominent spectral lines of hydrogen, the primary chemical ingredient of the universe.

Answer: D

9) In principle, if we could see all the way to the cosmological horizon we could see the Big Bang taking place. However, our view is blocked for times prior to about 380,000 years after the Big Bang. Why?

A) Before that time, the universe was too crowded with stars.

B) Before that time, the gas in the universe was dense and ionized and therefore did not allow light to travel freely.

C) Before that time, the universe was dark so there was no light to illuminate anything.

D) 380,000 years after the Big Bang marks the time when stars were first born, and thus began to shine the light by which we can see the universe.

Answer: B

10) If observations had shown that the cosmic microwave background was perfectly smooth (rather than having very slight variations in temperature), then we would have no way to account for

A) the relationship between the strong and the weak force.

B) the fact that our universe is expanding.

C) how galaxies came to exist.

D) the existence of helium in the universe.

Answer: C

11) In stars, helium can sometimes be fused into carbon and heavier elements (in their final stages of life). Why didn't the same fusion processes produce carbon and heavier elements in the early universe?

A) By the time stable helium nuclei had formed, the temperature and density had already dropped too low for helium fusion to occur.

B) Helium fusion occurred, but the carbon nuclei that were made were later destroyed by the intense radiation in the early universe.

C) Temperatures in the early universe were never above the roughly 100 million Kelvin required for helium fusion.

D) No one knows—this is one of the major mysteries in astronomy.

Answer: A

12) How does the idea of inflation account for the existence of the "seeds" of density from which galaxies and other large structures formed?

A) Inflation predicts that gravity would have been very strong and thereby would have concentrated mass into seeds.

B) Inflation tells us that the universe should have a "flat" overall geometry, and this led to the flat disks of galaxies.

C) Inflation predicts that temperatures and densities should have become nearly equal throughout the universe.

D) Inflation would have caused random, microscopic quantum fluctuations to grow so large in size that they became the seeds of structure.

Answer: D

13) Which of the following is *not* consistent with recent observations of the cosmic microwave background by the WMAP satellite?

A) The universe is geometrically "flat" (in the four dimensions of spacetime).

B) The matter density (both luminous and dark matter combined) in the universe is only about one-fourth of the critical density.

C) Dark energy, whatever it is, represents the majority of the energy content of the universe.

D) The universe is at least 20 billion years old.

Answer: D

14) Based on the results from the WMAP satellite, the overall composition of the universe is

A) 100% ordinary (baryonic) matter.

B) 15% ordinary (baryonic) matter, 85% nonbaryonic dark matter.

C) 1% ordinary (baryonic) matter, 99% nonbaryonic dark matter.

D) 4% ordinary (baryonic) matter, 23% nonbaryonic dark matter, 73% dark energy.

Answer: D

15) Which adjective does *not* necessarily describe a known feature of the early universe? (Be sure to consider the universe as a whole, not just the observable universe.)

A) dense

B) small

C) hot

D) filled with intense radiation

Answer: B

16) The Big Bang theory seems to explain how elements were formed during the first few minutes after the Big Bang. Which hypothetical observation below (these are *not* real observations) would call our current theory into question?

A) the discovery of a star-like object made entirely of carbon and oxygen

B) the discovery of a planet that with no helium in its atmosphere

C) the discovery of a galaxy with a helium abundance of only 10% by mass

D) the discovery of a galaxy with 27% helium rather than the 25% that theory tells us was produced in the Big Bang

Answer: C